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Method for drilling a well

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METHOD FOR DRILLING A WELL

The present invention relates to a method for drilling a well in an underground formation. In particular the invention relates to a method in which drill-in fluids are being applied.

5 In drilling operations a drill bit is usually attached to a drill pipe, which is then rotated to penetrate a formation thus forming a borehole. A drilling fluid can be circulated through the drill pipe, around the drill bit and back to the surface via the annulus
10 created between the drill pipe and the borehole. The purpose of the drilling fluid includes the cooling and lubrication of the drill bit and the removal of the cuttings from the borehole. The drilling fluid further provides a hydrostatic pressure against the borehole wall
15 to prevent fluids from the surrounding formation to flow into the borehole. The hydrostatic pressure is then higher than the fluid pressure in the surrounding formation. The pressure difference between the hydrostatic pressure of the drilling fluid and the fluid
20 pressure in the formation is also referred to as overbalance. Moreover, drilling fluids form a thin, low permeability filter cake, which seals small pores and other orifices in the borehole wall, thereby also preventing the influx of formation fluids. The
25 low-permeable filter cake will allow passage of the liquid phase (make-up fluid) of the drilling fluid or filtrate into the surrounding formation. Preferably, the passage is at as low a rate as possible. The rate

parameter of passage of make-up fluid is also described as the fluid loss control property of the drilling fluid.

5 A specific type of drilling fluid is the so-called drill-in fluid. That is a drilling fluid that is being used when the drilling occurs through that part of the formation that holds the gas or oil that is to be removed. In this specification this part will be referred to as the "production zone".

10 In US-A 5612293 a drill-in fluid has been described. This fluid has been designed to provide a particular density and a particular viscosity. The drill-in fluid comprises so-called bridging agents, in particular small sized calcium carbonate and/or sodium chloride particles. These agents seal off the porous reservoir rock in the borehole. That is desired to prevent near-well bore damage. However, in the production zone, the sealing of the borehole wall by the bridging agents hinder the influx of oil and/or gas into the bore hole for production. Therefore it is common to subject the
20 production zone to a remedial treatment, such as acidizing, by which at least some of the bridging agents are removed. It is evident that such a treatment adds significantly to the costs of the drilling and production operations. Moreover, complete removal of the bridging agents is often not achieved, resulting in a reduced well
25 productivity.

30 It has now surprisingly been found that the fluid loss control property of drill in fluids can be significantly improved by the replacement of inorganic bridging agents by solid oil-soluble resin particles. Accordingly, the present invention provides a method for drilling a well in an underground formation that contains a production zone, from which oil or gas can be produced,

comprising drilling a well into the formation until a production zone is reached using a drill bit, and introducing a drill-in fluid into the well when the production zone is reached; wherein the drill-in fluid comprises solid resin particles that are soluble in oil. The invention has the advantage that the fluid loss control is significantly improved with the formation of a very thin and extremely low-permeable filter cake. Thereby these drill-in fluids are extremely suitable when the hydrostatic pressure of the drill-in fluids is significantly higher than the fluid pressure in the surrounding formation. A further major advantage of this invention is that when the resin particles in a low-permeable filter cake seal off the wall of the production zone the influx of oil upon initiation of the well production gradually dissolves the bridging agents so that optimal unhindered production may take place. In this way additional remedial treatment steps have been avoided.

The drill-in fluid can be the same as the drilling fluid for the rest of the borehole. It is, however, advantageous to select the optimal composition for the drilling fluid before the production zone is reached and adapt the composition of the drilling fluid when it is to be used as the drill-in fluid. Drilling fluids suitably contain a number of agents for various purposes. Viscosifying polymers may be present to enhance the viscosity. Solids may be present to increase the density. The solid resin particles in the method of the present invention are suitably present in the form of a suspension. The concentration of the solid resin particles may vary as will be appreciated by the skilled artisan. Preferably, the suspension of solid particles is

relatively high, e.g., between 1 and 15 %vol, based on the total drill-in fluid. More preferably, the concentration is between 3 and 10 %vol. The suspension is suitably in an aqueous environment. The aqueous phase may be relatively pure water. However, since it is advantageous to increase the density of the aqueous phase and thereby the density of the drilling fluid, the drill-in fluid suitably comprises aqueous brine. The brine may contain monovalent and multivalent ions. In order to keep the solid resin particles well suspended it is advantageous to include in the drill-in fluid one or more surfactants. Many surfactants can be used to keep the solids suspended. Examples of surfactants include anionic, non-ionic and cationic surfactants. Anionic surfactants may be selected from the group consisting of alkyl aryl sulphonates, such as C₄-18 alkyl phenyl sulphonic acid or alkali metal salts thereof, e.g., dodecyl benzene sulphonic acid, and alkyl sulphates, such as sodium lauryl sulphate. Examples of non-ionic surfactants include polymers of alkylene oxides, such as ethylene oxide and/or propylene oxide, polyalkoxide derivatives of alkyl phenols, or polyols such as glycerol, or carbohydrates, such as sorbitol, and glycosides. Examples of cationic surfactants include quaternary ammonium compounds such as tetraalkyl ammonium salts of carbonic acids, e.g. of formic, acetic, propionic or butyric acid. At least one alkyl chain in these cationic surfactants suitably contains more than 6 carbon atoms, e.g. from 6-18 carbon atoms. The preparation of the drill-in fluid is facilitated when an aqueous suspension of solid resin particles is used that also comprises at least one surfactant.

In order to seal off the borehole efficiently, it is preferred that the solid resin particles have a specific particle size distribution. A person skilled in the art will realise that the nature and origin of the reservoir rock have an influence on the desired particle sizes. In this respect the openings of the pores in the surrounding formation play a role. Preferably the average particle size is at least $1/7$ of the size of the average pore opening ("throat") in the formation. More preferably, the average particle size is between $1/3$ and $1/1$ of the average pore opening of the formation. In this way the bridging effect is made optimal.

It has further been found that good results are obtainable when the solid resin particles have a particle size distribution wherein (i) at least 90 volume per cent of the solid resin particles have an average major axis of 40 micrometer or less, and (ii) at least 10 volume per cent of the solid particles have an average major axis diameter of 2 micrometer or less.

The solid particles are solid resin particles. This implies that they consist of a polymeric material that is soluble in oil. The person skilled in the art may select the appropriate resin in accordance with the solubility thereof in the oil that is present in the surrounding formation. It is preferred that the solubility of the resin in the oil is at least 5 g/l at 50 °C, more preferably at least 10 g/l. Hydrocarbon wax, as a non-soluble, inherently soft material is not included in this definition. Preferably the solid resin comprises silicone resin. Although it is known to use silicones in drilling fluids (see e.g., US 5707939 and US-A 5712228) the silicones used in the published applications relate to silicone fluids. Hence, a major difference with the

present invention compared to the published use of
silicone compounds is the use of solid silicone resin
particles. It is evident that with the solid particles a
satisfactory bridging effect can be obtained which is not
possible with the use of silicone oil. The silicone resin
used in the method of the invention suitably includes
monovalent monofunctional M units ($R_3SiO_{1/2}$), divalent
difunctional D units ($R_2SiO_{2/2}$), trivalent trifunctional
T units ($RSiO_{3/2}$), and tetravalent Q units ($SiO_{4/2}$), in
which R is hydrogen, hydroxyl, a monovalent hydrocarbon
group having 1 to 8 carbon atoms, an alkoxy group with up
to 8 carbon atoms, or a substituted monovalent
hydrocarbon group with up to 8 carbon atoms. The silicone
resin is a silicon-containing non-linear oligomer or
polymer that includes trivalent T units and tetravalent Q
units as the principal building blocks of its network.
Divalent D units may be included to modify the resin
structure. Suitably, the structures of this type are end-
capped with monovalent M units. It is preferred that the
silicone resin consists of M and Q units. The molar ratio
of M units to Q units is preferably from 0.4:1 to 1.7:1,
more preferably from 0.6:1 to 1.5:1. Most preferred, the
molar fraction of M units in the silicone resin is from
0.38 - 0.43 and the fraction of Q units is 0.62 - 0.57.

Examples of suitable groups R include alkyl groups
such as methyl or ethyl; aryl groups such as phenyl or
naphthyl; alkenyl groups such as vinyl, allyl, 5-hexenyl
and cyclohexenyl; aryl alkyl groups such as phenyl
methyl, phenyl ethyl, phenyl propyl and phenyl hexyl;
alkoxy groups such as methoxy, ethoxy and propoxy; and
hydrocarbon groups substituted with halides, in
particular fluorine, such as trifluoromethyl,

trifluoroethyl and trifluoropropyl groups. Most preferred the group R is methyl.

The residual hydroxyl content of the silicone resin is advantageously limited. It is suitably less than 15 mole percent, with more preference less than 5, and even more with less than 3.5 weight percent as determined by Nuclear Magnetic resonance. (NMR).

The weight average molecular weight of the silicone resin is selected such that the resin is solid at least until a temperature that prevails in the borehole. Preferably, the silicone resin has a melting point of at least 250 °C. The weight average molecular weight of the silicone resin is advantageously selected between 8,000 and 30,000, as determined by gel permeation chromatography.

Depending on the nature of group R, silicone resins can maintain solubility in hydrocarbons across a wide range of molecular weights. Silicone resins with a large proportion of Q units additionally exhibit very high glass transition temperatures. Very high glass transition temperatures possessed by silicone resins allow borehole fluids to be used at temperatures far higher than comparable fluids formulated with the use of organic solids containing no silicon atoms. When a particle size distribution such as the one described above is used in an organic resin containing no silicon atoms, and the organic resin is tested at temperatures below its glass transition temperature, its performance is similar to that obtained with the silicone resin. However, when the organic resin without silicon atom is tested at temperatures above its glass transition temperature it fails in performance under standard fluid loss test protocols. Suitably the glass transition temperature of

the silicone resin is at least 70 °C, more preferably above 150 °C, most preferably from 150 °C to 250 °C.

The concentration of the solid resin particles in the drill-in fluid may be selected between wide ranges, as can be determined by the person skilled in the art.

Factors that may influence the concentration include the depth of the borehole and the temperature associated therewith and the pressure difference between the hydrostatic column and the fluid pressure in the

reservoir. It has been found advantageous to work with a drill-in fluid containing from 2 to 8, preferably from 3 to 6 %vol of solid resin particles, based on the total volume of the drill-in fluid.

The drill-in fluid used in the method of the present invention suitably comprises several other additives to give it the desired properties. It has already been mentioned that the fluid contains a brine and

surfactants. The brine may comprise several salts. The brine suitably contains alkali metal halide e.g., sodium chloride, potassium chloride, sodium bromide, potassium bromide or alkali metal formate, such as sodium,

potassium or caesium formate. It is especially preferred to add alkali metal formate to the drill-in fluid to increase the density. Mixtures of these salts may also be used. The density of the drill-in fluid is suitably from 1.0 to 2.50 g/cm³, preferably from 1.1 to 2.2 g/cm³.

Inorganic compounds may be added to maintain the alkalinity of the drill-in fluid. It is envisaged that a drill-in fluid containing silicone resin particles does not contain any other inorganic solid particles as bridging agents such as calcium carbonate, or weighting material, such as barium sulphate. However, the combined

application of both solid resin particles blended with such inorganic particles is feasible.

Other additives include viscosifiers, in particular xanthan gum, guar gum, or cellulose-derived polymers such as methylcellulose, hydroxy propyl methylcellulose, and hydroxy ethyl cellulose, starch and starch amylose. Additives such as carboxymethyl starch, carboxymethyl cellulose and polyanionic cellulose are particularly suitable to enhance the fluid loss control property of the drill-in fluid. The carrier liquid in the suspension can also be varied. Although a water base is desirable, it is possible to add water-miscible components as carrier fluid for the silicone resin. Examples include polyols such as ethylene glycol, propylene glycol, trimethylene glycol, glycerol, and polyethylene glycol or polypropylene glycol (suitably with a number average molecular weight from 200 to 1,000), or glycerol esters, such as glyceryl triacetate, tripropionate or tributyrate.

EXAMPLE 1

An excess of silicone resin (ex Dow Corning) was added to 100 ml of Oman crude oil at 50 °C. The mixture was kept at this temperature overnight whilst maintaining turbulence, and the excess solids were filtered off. It appeared that the solubility of the silicone resin in Oman crude oil was 24.8 g/l.

EXAMPLE 2

In this example the fluid-loss control property of various drill-in fluids was tested. All drill-in fluids were based on 3 %w KCl solution mimicking brine. Other constituents of the drill-in fluids are indicated in Table 1. The average pore size of the filter press was 10 micrometer. The silicone resin used had an average

particle size of 5 μm . It was added in the form of an aqueous dispersion, containing 35 %v of silicone resin.

The calcium carbonate particles used in some drill-in fluids had an average particle size of 9.2 μm .

5 The drill-in fluids were tested over a filter press at 85 °C at a differential pressure of 34.5 bar over a maximum of 30 minutes. The number of millilitres of fluid passed through the filter press was considered a measure of the fluid-loss property of the drill-in fluid.

TABLE 1

Fluid No.	Other constituents	Amount
1	xanthan gum calcium carbonate	2.85 g/l 5 %v (on total fluid)
2	xanthan gum silicone resin	2.85 g/l 5 %v (on total fluid)
3	xanthan gum polyanionic cellulose calcium carbonate	2.85 g/l 5.7 g/l 5 %v (on total fluid)
4	xanthan gum polyanionic cellulose silicone resin	2.85 g/l 5.7 g/l 5 %v (on total fluid)
5	xanthan gum calcium carbonate	5.7 g/l 5 %v (on total fluid)
6	xanthan gum silicone resin	5.7 g/l 5 %v (on total fluid)

The results are indicated in Table 2

TABLE 2

Fluid No.	Number of millilitres filtrate after 30 minutes
1	Not determined (already 50 ml after 10 min.)
2	34
3	42
4	21
5	33
6	18

EXAMPLE 3

Scouting tests to determine the effect of silicone resin particles on the permeability of 90-150 mD Berea sandstone rock cores were conducted. In these tests the cores were either saturated with filtered brine (3 %wt KCl in water) or hydrocarbon fluid, followed by the determination of the original permeability with the same fluid. The cores were subsequently exposed to a drill-in fluid at an overbalance of 13.8 bar for 30 minutes after which the return permeability was measured. With the hydrocarbon in the core, the core was left to soak in the hydrocarbon fluid for 16 hours, followed again by a return permeability measurement. All tests were carried out at ambient temperature.

The composition of the drill-in fluid was as follows: 3 %wt KCl brine with 2.85 g/l xanthan gum as viscosifier, 8.55 g/l polyanionic cellulose as fluid loss control agent, 5 %v silicone resin particles. The fluid was adjusted to a pH of 9 by sodium hydroxide. To some of the fluids were added 45 g/l calcium montmorillonite to

simulate drilled solids. The average particle size of the silicone resin was 9 μm .

For comparison substantially the same composition of the drill-in fluid was used, the only difference being that silicone resin has been replaced by calcium carbonate. The average particle size of the calcium carbonate was 9.2 μm . The results are shown in Table 3.

TABLE 3

Type of bridging solids/ drilled solids(yes/no)/ formation fluid	Permeability (mD)		
	Initial	Return	%Loss
CaCO ₃ /no solids/brine	105.1	32.4	69.2
CaCO ₃ /yes solids/brine	104.1	40.3	61.3
Resin/no solids/brine	90.9	34.9	61.5
Resin/no solids/oil	146.6	66.1	54.9
Resin/yes solids/brine	97.3	50.1	48.5
Resin/yes solids/oil	136.8	130.7	4.5

C L A I M S

1. Method for drilling a well in an underground formation that contains a production zone, from which oil or gas can be produced, comprising drilling a well into the formation until a production zone is reached using a drill bit, and introducing a drill-in fluid into the well when the production zone is reached; wherein the drill-in fluid comprises solid resin particles that are soluble in oil.
2. Method according to claim 1, in which the solid resin is present in the form of a suspension.
3. Method according to claim 1 or 2, in which the drill-in fluid comprises an aqueous brine.
4. Method according to one or more of claims 1 to 3, in which the drill-in fluid also comprises at least one surfactant.
5. Method according to claim 4, in which the surfactant is selected from the group consisting of anionic, non-ionic and cationic surfactants and mixtures thereof.
6. Method according to one or more of claims 1 to 5, in which the drill-in fluid comprises solid resin particles with a particle size distribution wherein (i) at least 90 volume per cent of the solid resin particles have an average major axis of 40 micrometer or less, and (ii) at least 10 volume per cent of the solid particles have an average major axis diameter of 2 micrometer or less.
7. Method according to one or more of claims 1 to 6, in which the solid resin comprises silicone resin.
8. Method according to claim 7, in which the silicone resin includes monovalent monofunctional M units

($R_3SiO_{1/2}$), divalent difunctional D units ($R_2SiO_{2/2}$),
trivalent trifunctional T units ($RSiO_{3/2}$), and
tetravalent Q units ($SiO_{4/2}$), in which R is hydrogen,
hydroxyl, a monovalent hydrocarbon group having 1 to
5 8 carbon atoms, an alkoxy group with up to 8 carbon
atoms, or a substituted monovalent hydrocarbon group with
up to 8 carbon atoms.

9. Method according to claim 7, in which the silicone
resin contains only monofunctional M units ($R_3SiO_{1/2}$) and
10 tetravalent Q units ($SiO_{4/2}$), in which R is hydrogen,
hydroxyl, a monovalent hydrocarbon group having 1 to
8 carbon atoms, an alkoxy group with up to 8 carbon
atoms, or a substituted monovalent hydrocarbon group with
up to 8 carbon atoms.

15 10. Method according to one or more of claims 7 to 9, in
which the silicone resin contains no more than 15 mole
percent hydroxyl as determined by NMR, the number ratio
or molar fraction of M units to Q units being in the
range of 0.4:1 to 1.7:1, and the weight average molecular
20 weight of the silicone resin being from 8,000 to 30,000
as determined by gel permeation chromatography.

11. Method according to one or more of claims 1 to 10, in
which the glass transition temperature of the resin
particles is at least 70 °C

25 12. Method according to one or more of claims 1 to 11, in
which the drill-in fluid also comprises inorganic
material blended with the solid resin particles.

13. Method according to one or more of claims 1 to 12, in
which the drill-in fluid has a density of 1.1 to
30 2.2 g/cm³.

A B S T R A C T

METHOD FOR DRILLING A WELL

A method for drilling a well in an underground formation that contains a production zone, from which oil or gas can be produced, comprises drilling a well into the formation until a production zone is reached using a drill bit, and introducing a drill-in fluid into the well when the production zone is reached; wherein the drill-in fluid comprises solid resin particles that are soluble in oil. The solid resin preferably comprises silicone resin.

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